SPECIAL REPORT SR-2002-005

RESEARCH AND DEVELOPMENT ISSUES FOR ADVANCED INTERACTIVE ELECTRONIC TECHNICAL MANUALS

JULY 2002

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REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget. Paperwork Reduction Project (0704-0188), Washington, DC 20503.			
1. AGENCY USE ONLY (*Leave Blank)*	2. REPORT DATE 15 July 2002	3. REPORT TYPE AND DATES COVERED Special Report (01 Oct 2001 to 15 July 2002)	
4. TITLE AND SUBTITLE Research and Development Issues for Interactive Electronic Technical Manuals			5. FUNDING NUMBERS PE0602236N
6. AUTHOR(S) Katrina Ricci, Paul Radtke, and John Hodak			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NAVAIR Orlando, Training Systems Division 12350 Research Parkway Orlando, FL 32826			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) ONR 800 N. Quincy Street Arlington, VA 22217-4318			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE
13. ABSTRACT (*Maximum 200 words*) The Capable Manpower program of the Office of Naval Research's Future Naval Capabilities program is supporting research addressing the needs of the technical manual community. While there is a wide range of research issues associated with technical manuals, the focus of the Intelligent Performance Support and Training effort is the development and evaluation of various technologies to support Interactive Electronic Technical Manuals (IETMs). A workshop was conducted at the NAVAIR Orlando, Training Systems Division to discuss the domain and to present current research in this area. The purpose of this report is to document the proceedings of the workshop and further define the goals, technologies, and issues related to this research effort. Specific research areas include the use of device models and intelligent tutors, the application of Latent Semantic Analysis for search and navigation within an IETM, and spoken language interfaces and wearable computers to support hands-free use.			
14. SUBJECT TERMS Interactive Electronic Technical Manuals (IETMs); Intelligent Tutoring; Device Models; Wearable Computers; Search and Navigation; Latent Semantic Analysis			15. NUMBER OF PAGES 35 16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unclassified

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18

EXECUTIVE SUMMARY

For a number of reasons, technical publications for military systems are now delivered as, or converted to, electronic format. These reasons include limiting space and weight, providing timely access to technical information and timely updates, and avoiding deterioration common to paper products. However, there are a number of problems that can make today's electronic documents less than acceptable. Limited access to computer support, complex and unintuitive user interfaces, poor presentation of graphics or diagrams, and restricted mobility for technicians are just some of the issues that force maintenance personnel to revert to paper versions of technical manuals. In order to discuss the domain and to present current research in this area, a workshop was conducted 23 January 2002 at the NAVAIR Orlando, Training Systems Division. The purpose of this report is to highlight the proceedings of the workshop and further define the goals, technologies, and issues related to this research effort.

The following is a list of presentations given during the workshop:

Human Factors in Naval Aviation Maintenance Related Mishaps: Focus on Publications, CDR John Schmidt, Naval Safety Center

IETM Development and Intelligent Diagnostics, Dr. Douglas Towne, University of Southern California/Behavioral Technology Laboratory

Advance Search and Display: Dynamic SuperManuals with Latent Semantic Analysis, Dr. Thomas Landauer, Knowledge Analysis Technologies

Spoken Language Dialog and Improved, Adaptive Design of Advanced IETM Interfaces, Dr. Alex Rudnicky and Dr. Jane Siegel, Carnegie Mellon University

Maintenance Support Technologies, Mr. Mike Kendall, Task-Based Technologies, Inc.

The Use of IETMs for Operations, Doctrine, and Training, TMCM (EOD) Mark Nelson, COMEODGRU TWO

As part of the Capable Manpower Future Naval Capabilities (FNC) program, the Office of Naval Research (ONR) is supporting a research effort addressing the needs of the technical manual community. While there is a wide range of potential research issues associated with technical manuals, the focus of the Intelligent Performance Support and Training effort is the development and evaluation of various technologies to support Interactive Electronic Technical Manuals (IETMs). These technologies include: the use of device models and intelligent tutors to exploit the use of computers in aiding and training technicians through their IETM; the use of a machine learning

technology, Latent Semantic Analysis, to assist in search and navigation tasks within an IETM; and the use of wearable computers and spoken natural language dialogs to support a voice-activated, hands-free working environment.

The first section of this report describes current issues related to the use of technical manuals in general, and more specifically, problems associated with the current generation of IETMs. The next three sections provide descriptions of the research areas within the Intelligent Performance Support and Training effort. The final section of this report describes issues raised during workshop discussions.

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INTRODUCTION

As part of the Capable Manpower Future Naval Capabilities (FNC) program, the Office of Naval Research (ONR) is supporting a research effort addressing the needs of the technical manual community. While there is a wide range of potential research issues associated with technical manuals, the focus of the Intelligent Performance Support and Training effort is the development and evaluation of various technologies to support Interactive Electronic Technical Manuals (IETMs). A workshop was conducted 23 January 2002 at NAVAIR Orlando, Training Systems Division, to discuss the domain and to present current research in this area. The purpose of this report is to document the proceedings of the workshop and further define the goals, technologies, and issues related to this research effort.

Recently, technical publications for military systems are being delivered with, or converted to, electronic format. Space and weight issues related to storage and transfer of technical manuals are the primary driving forces behind conversion to electronic format. Whether the technician is deployed in the field, working on the flight line, or stationed onboard a ship, these issues are critical. This is exacerbated by the fact that many present day systems are complex and interconnected – making maintenance documentation that much more "bulky". Quick access to critical information, without the need for thumbing through volumes of documentation, is highly appealing. Furthermore, updates to paper documentation due to system changes or revealed errors are cumbersome under the best of circumstances and all too often not performed or unseen in others. This leaves the technician operating with out-dated or erroneous information that may, in some cases, prove dangerous to the technician or operators. Other relevant issues include the fact that by its very nature, paper deteriorates and may do so rapidly in harsh, military environments. Electronic documentation aids in the updating process and ensures that the document remains intact.

There are two types of electronic technical publications: the Electronic Technical Manual (ETM) and the Interactive Electronic Technical Manual (IETM). While the term ETM can encompass *all* forms of electronic documentation, it is typically used to refer to raster scanned, page oriented documents or Standard Generalized Markup Language (SGML) tagged scrolling documents that may contain internal hyperlinks. The IETM is a more sophisticated, interactive electronic document that includes links to external resources, such as diagnostic aids or training materials, and can be hierarchically structured to capitalize on data reuse. IETMs are categorized as classes one through five. A more specific description of the classifications of ETMs and IETMs is provided in Table 1.

	Basic ETMs	IETMs			
	Class I	**Class II**	**Class III**	**Class IV**	**Class V**
	Electronically Indexed Pages	Electronic Scrolling Documents	Linearly Structured IETMs	Hierarchically Structured IETMs	Integrated Database
DISPLAY	• Full page viewing • Page-turner/Next function • Intelligent index for user access to page images • Page integrity preserved	• Primary view is scrolling text window • Hot-spot access (Hyper-links) to other text or graphics • User selection and navigation aids (key-word search, on-line indices) • Minimal text-formatting for display • User selectable call to (launch) another process	• View smaller logical blocks of text - less use of scrolling • Interaction through dialog boxes • Interaction per Mil-PRF-87268 to extent possible • Text and graphics simultaneously displayed in separate window when keyed together	• View smaller logical blocks of text - very limited use of scrolling • Interaction through dialog boxes with user prompts • Interaction per Mil-PRF-87268 • Text and graphics simultaneously displayed in separate window when keyed together	• Class IV IETM functions • Interactive electronic display per Mil-PRF-87268 • Multi-function display session • Expert system allows same display session and view system to provide simultaneous access to many differing functions (e.g., supply, training, troubleshooting)
DATA FORMAT	• Bit Map (raster) • Indexing and header files (Navy Mil- 29532) • MIL-PRF-28001 or Postscript • Generic: C/NDI imaging system formats	• Text - ASCII or PDF • Graphics - whatever viewer supports - e.g., BMP or CALS • Can be SGML tagged - no page breaks (browser) • Access/index often C/NDI dependent with HyperText browser • Generic: C/NDI with HyperText browser	• Linear ASCII with SGML tags • SGML with content vice format tags • Maximum use of Mil-PRF-87269 • Generic: SGML tags equivalent to Mil-PRF-87269 tags	• Fully attributed database elements (Mil-PRF-87269) • Mil-PRF-87269 content tags with full conformance with Generic Level Object Out-lines (architectural forms) • Authored directly to DB for interactive electronic output • Data managed by a DBMS • Interactive features authored-in vice added-on • Generic: C/NDI has Mil-PRF-87269 data definition/tags	• IETM info integrated at the data level with other application info • Does not use separate databases for other application data • Identical to Class IV standards for IETM applications data per Mil-PRF-87269 • Coding for Expert Systems and AI modules when used • Generic: C/NDI has Mil-PRF-87269 data definition/tags
FUNCTIONALITY	• Access pages by intelligent index/ header info • View page with pan, zoom, etc tools • Limited use of hot-spots • Useful for library or reference use	• Browse through scrolling info • User selection of graphics or hot-spot reference to more text • Hot-spot and cross-reference usually added after original authoring	• Dialog-driven interaction • Logical display of data in accordance with content • Logical NEXT and BACK functions • Useful as interactive maintenance aid • User-selectable cross-refs and indices • Content specific help available	• Dialog-driven interaction • Logical display of data in accordance with content • Logical NEXT and BACK functions • Useful as interactive maintenance aid • User-selectable cross-refs and indices • Content specific help available	• Single viewing system for simultaneous access to multiple info sources • Same as Class IV for IETM functions • Expert system to assist in NEXT functions, based on info gathered in session

Table 1. IETM Classes (Defense Systems Management College Press, 1999).

The notion of electronic documentation is not new. From the Navy's perspective, the push for electronic documentation began in the 1980's with the notion of the "paperless ship." In fact, there are many systems that are and have been supported by electronic documentation for some time. Further, there is a wide range of characteristics that an electronic document may possess and there are a number of vendors of IETM authoring and viewing products. There also are standards and guidelines available that aid in producing electronic documentation. For example, MIL-PRF-87268A describes how an IETM should look and behave for the reader and MIL-PRF-87269 describes database forms, structure and key IETM controlling mechanisms.

PROBLEMS

Given the need for electronic documentation, the availability of tools for development and delivery, and the existing guidance, it is surprising that IETM applications often go unused. There are instances where basic problems interfere with a technician's ability to use an IETM. For example, an IETM may not be used on the job because the activity lacks computing power to run the IETM. Simply stated, it is difficult to work with today's technology on a 386 computer. However, more complex and pervasive issues, such as the poor usability of the documentation or computer interface or limited skill levels of technicians, can also lead to under-utilization of what should be a valuable resource.

Usability Issues

Maintenance manuals contribute to maintenance error if they contain misleading information, insufficient information, or unclear procedures (Chaparro & Groff, 2001). In IETMs, the navigational environment is also critical. If a document's interface is too complex and the navigation is unintuitive, users have difficulty finding and following documented direction. Usability, defined as "the ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component" (IEEE, 1990), will impact a user's ability and willingness to refer to the document.

Problems with maintenance manuals are not new. User's perceptions of the utility of a manual can apply equally to paper-based documents and electronic documents. In a study conducted for the Australian Transportation Safety Bureau,

- 67% of respondents reported having been misled by maintenance documentation,
- 47% reported having opted to perform a maintenance procedure in a way they felt was superior to that described by the manual, and
- 73% of mechanics surveyed reported failing to refer to maintenance documents either occasionally or often (Hobbs & Williamson, 2000; Chaparro & Groff, 2001).

It must be assumed that these same problems are also inherent in electronic documentation. Adding to that, the navigational environment within the IETM can also be problematic. If an electronic document is too complex and unintuitive, the user will revert to older paper copies, or choose to ignore prescribed documentation entirely. Therefore, an IETM must provide information that is not only correct, it must allow the user to access that information easily and in a timely manner.

Unfortunately, current capabilities predominantly utilize computers as a *substitute for paper* rather than capitalizing on computing resources. Often, the information that a technician needs is embedded within complex diagrams and schematics. On paper, they are static representations. On the computer, not much changes – and worse, these drawings are difficult to view due to size and screen constraints.

Finally, the working environment may not be conducive to the use of a PC or laptop. Working in small, confined spaces (e.g., underneath a large, tracked vehicle) or in environmentally harsh conditions (e.g., the engineering spaces onboard a ship or a loud flight line) provides little room and poor habitability for conventional computers.

Data briefed at the NAVAIR workshop indicate that in the last decade, approximately 600 mishaps in U.S. Naval Aviation had a maintenance casual factor. Of those, approximately 25% were at least partially due to a problem with publications (technical manuals). Considering that the average cost of each mishap is approximately $1M, there is a considerable cost factor involved. The Navy Safety Center, with support from this research effort, is currently refining data associated with publication errors in order to more accurately pinpoint problem areas within publications.

Skilled Workforce Decline

Further complicating the issues associated with IETM usability is the declining level of expertise of the typical maintenance technician. While comparable data are not available to represent the surface navy, data from industry are directly relevant and mirrors that of the naval aviation maintenance workforce. The Labor Department reports that approximately 140,000 mechanics work in the aviation industry today and 40,000 additional mechanics will be needed by 2008. In order to fill positions necessary to support larger fleets, maintenance facilities are being forced to lower hiring requirements for maintenance personnel. As an example, American Airlines has recently been forced to lower experience requirements from 4 to 2 years (Chaparro, 2001).

In a similar trend, the Navy's Aviation Depots have recently consolidated and, over the past decade, considerably reduced the number of new hires. As a consequence, there is a wealth of experience that is now ready to retire. As they retire,

these senior technicians take with them that corporate knowledge of their jobs that is not represented in their technical publications.

While not the result of an aging workforce, the surface navy has similar issues with the skill level of maintenance technicians. Trends in new ship design are capitalizing on increased automation in order to minimize shipboard manning. Manpower is the single greatest lifecycle cost for each ship. Thus, programs such as DD(X) and CVN(X) are making great efforts to decrease the number of personnel onboard. While not as dramatic, the LPD 17 San Antonio Class – the Navy's next generation amphibious warfare platform – has also made considerable efforts to optimally man each ship. The consequences of these trends equate to the need to empower technicians to generalize their skills beyond any one system. The ability to provide this empowerment through the use of a technician's technical manual, a major goal of the current effort, requires the addition of performance supporting mechanisms, learning opportunities and a highly intuitive user interface.

Summary

The move of technical manuals to the electronic environment has been driven by practical, logistical requirements. Now, however, there is a need to thoroughly examine the role of electronic documentation for the end user. It is remarkable that although the technologies embodied within IETMs are prevalent in other common, often-used systems (e.g., Internet), there is a dearth of research literature related to the use of these tools. Where currently electronic documentation may hinder the work of maintenance personnel, future products must exploit the capabilities of computers to aid technicians. Further, it is obvious that different contexts, domains, and tasks require different delivery methods and varying displays of information. It is critical for the research community to specify those relationships and provide the acquisition community with the knowledge to purchase the right system for the right job.

ONR began highlighting issues related to use of IETMs under the Condition-Based Maintenance (CBM) program. Three ONR sponsored workshops conducted between 1998-1999 addressed the topics of Machinery Prognostics, Personalized Maintainer, and Generalized Maintainer. In particular, the Personalized and Generalized Maintainer Workshops specified Science and Technology (S&T) issues and opportunities and identified potential development paths for enhancing the technology and encouraging its use. While more focused on the interaction of IETMs with CBM technology, there were a number of issues documented that are directly related to current efforts. Of the five themes addressed at the Generalized Maintainer Workshop, two are directly related to current research activities: 1) integrating training and performance aiding technologies and 2) expanding and refining enabling technologies. These issues will be addressed in subsequent sections of this report in the context of the current research program.

INTELLIGENT PERFORMANCE SUPPORT AND TRAINING

To focus research on technical manual issues such as those related above, a program of research was proposed under ONR's Capable Manpower Future Naval Capabilities (FNC) Program. This effort, Intelligent Performance Support and Training, is an Enabling Capability of the Objective-Based On-the-Job Training Supporting Capability. The product associated with this effort is an authoring capability that will allow developers to build IETMs that integrate three technologies that will be further developed and evaluated under this program. Specific research areas include:

- the use of device models and intelligent tutors;
- the application of Latent Semantic Analysis (*LSA*) for search and navigation within an IETM; and
- spoken, natural language processing and wearable computers technologies to support hands-free use.

The Research and Development Issues Associated with Interactive Electronic Technical Manuals Workshop, held at NAVAIR Orlando, Training Systems Division January 23 2002, served as a kick-off meeting for the Intelligent Performance Support and Training program. The goal of the workshop was to present current and planned research that addressed topics related to IETMs. Members of the academic community and industry as well as fleet representatives provided briefings. The workshop agenda is shown in Table 2. A list of workshop participants is provided in Appendix A.

Three of the presentations provided at the workshop are associated with the current FNC research effort. Those presentations included: "IETM Development and Intelligent Diagnostics," Dr. Doug Towne; "Advance Search and Display: Dynamic *SuperManuals* with Latent Semantic Analysis," Dr. Tom Landauer; and "Spoken Language Dialog and Improved, Adaptive Design of Advanced IETM Interfaces," Dr. Jane Siegel and Dr. Alex Rudnicky. Thus, the following sections are provided as an overview of the background, goals, and products of each of these efforts.

Presentation	Speaker, Organization
Overview	Dr. Katie Ricci, NAVAIR Orlando
IETMs and Maintenance Safety Issues	CDR John Schmidt, Naval Safety Center
IETM Development and Intelligent Diagnostics/ Demonstration	Dr. Douglas Towne, University of Southern California/Behavioral Technology Laboratory
Advance Search and Display: Dynamic *SuperManual*s with Latent Semantic Analysis	Dr. Thomas Landauer, Knowledge Analysis Technologies
Spoken Language Dialog and Improved, Adaptive Design of Advanced IETM Interfaces	Dr. Alex Rudnicky and Dr. Jane Siegel, Carnegie Mellon University
Royal Navy Advanced IETM Pilot Study	Mr. Mike Kendall, Task-Based Technologies, Inc.
The Use of IETMs for Operations, Doctrine, and Training	TMCM (EOD) Mark Nelson, COMEODGRU TWO

Table 2: Workshop Agenda, Speakers, and Organizations

DEVICE MODELS AND INTELLIGENT TUTORING

For any given system, a technical manual provides the information needed to support a technician during planned or corrective maintenance activities. As the documented source of information for a system, the technical manual is very often the source of content for training applications. Thus, technical manuals and training are closely associated.

The training pipelines for Navy technicians can be fairly generic. For example, a broad technical area is presented (i.e., propulsion) but due to the wide range of systems in use in the navy, a specific propulsion system may not be taught. It is not unusual for a technician to arrive on station and be assigned to a system that is unfamiliar. Further, current reduced manning trends may require technicians to perform maintenance on a wider range of equipment than ever before. It is attractive, therefore, to embed training within a technical manual in order to alleviate gaps in training. In fact, current IETM applications may have links to training materials to support the technician. This concept is even specifically described in the Display of a Class V IETM: "...simultaneous access to many differing functions (e.g., supply, training, troubleshooting)" (See Table 1).

The notion of embedding training – in a traditional sense - within a technical manual is less than perfect. Time constraints usually prohibit technicians from stopping procedures until a training application is completed. Second, the building of expertise requires practice within the context of the actual system – a feature few electronic training applications will support. Attendee feedback from a previous Workshop held January 2000 at NAVAIR Orlando, overwhelmingly expressed the notion that Interactive Courseware (ICW) linked to an IETM would not be sufficient or useful for the technician when performing maintenance functions. However, a more comprehensive solution can be obtained when technicians are provided performance support as well as training opportunities. This concept, briefed at the 2002 workshop by Dr. Doug Towne, is embodied within the research efforts of the University of Southern California/Behavioral Technology Laboratory (USC/BTL) and is described below.

INTELLIGENT TUTORING FOR FAULT DIAGNOSIS

Intelligent tutors for fault diagnosis can be generalized as either knowledge engineering approaches or model-based approaches (Towne, 2002). Knowledge engineering approaches rely on subject matter expertise to build system specific knowledge for fault diagnosis. A notable example of a knowledge engineering approach to tutoring fault diagnosis is Sherlock (Lesgold, Eggan, Katz, and Rao, 2002; Lajoie and Lesgold, 1992). Although knowledge engineering approaches provide excellent tutors, they do so at a cost. The time and effort needed to elicit data and build the expert

system is quite intensive and can be particularly costly when addressing complex systems.

Unlike knowledge engineering approaches, model-based approaches represent the target system via a computer model that provides domain-specific functional information. This model is used in conjunction with a domain-free diagnostic reasoning capability. With this approach, the device itself is separate from the diagnostic capability. Thus, any system model that has the appropriate data to share with a diagnostic reasoning capability can benefit. In the current research, the intelligent tutoring and performance aiding functions make use of a model-based approach.

PROVIDING MODEL-BASED INTELLIGENT TUTORING WITHIN AN IETM

Over the past decade, ONR and other government agencies have provided considerable support in the development of interactive, simulation-based systems. The foundation of this work is the *VIVIDS* software (Munro, 1994; Towne, 1994). *VIVIDS* is a general-purpose simulation authoring system. *VIVIDS* applications are developed and delivered in a *LINUX/UNIX* operating system. In addition to *VIVIDS*, USC/BTL has developed a number of additional applications including two that are being applied to the current research program: *ReAct* and *DIAG*. Much like *VIVIDS*, *ReAct* is a general-purpose simulation authoring and presentation system. It produces a device model and maintains the graphical representation as the model changes state. Unlike VIVIDS, *ReAct* applications are produced employing Click 2 Learn's ToolBook in a Windows environment. Diagnostic Instruction and Guidance (*DIAG*) inspects the device model and generates intelligent diagnostic decisions and assessments.

In order to integrate the device models and intelligent tutors into an IETM, a control shell was developed. This shell, termed the Personal Knowledge System (*PKS*), allows the presentation of *ReAct* and *DIAG*, as well other media (e.g., Flash animation, speech technology, etc.). As shown In Figure 1, *PKS* is the primary interface between training or aiding media and the end user (Towne, 2001).

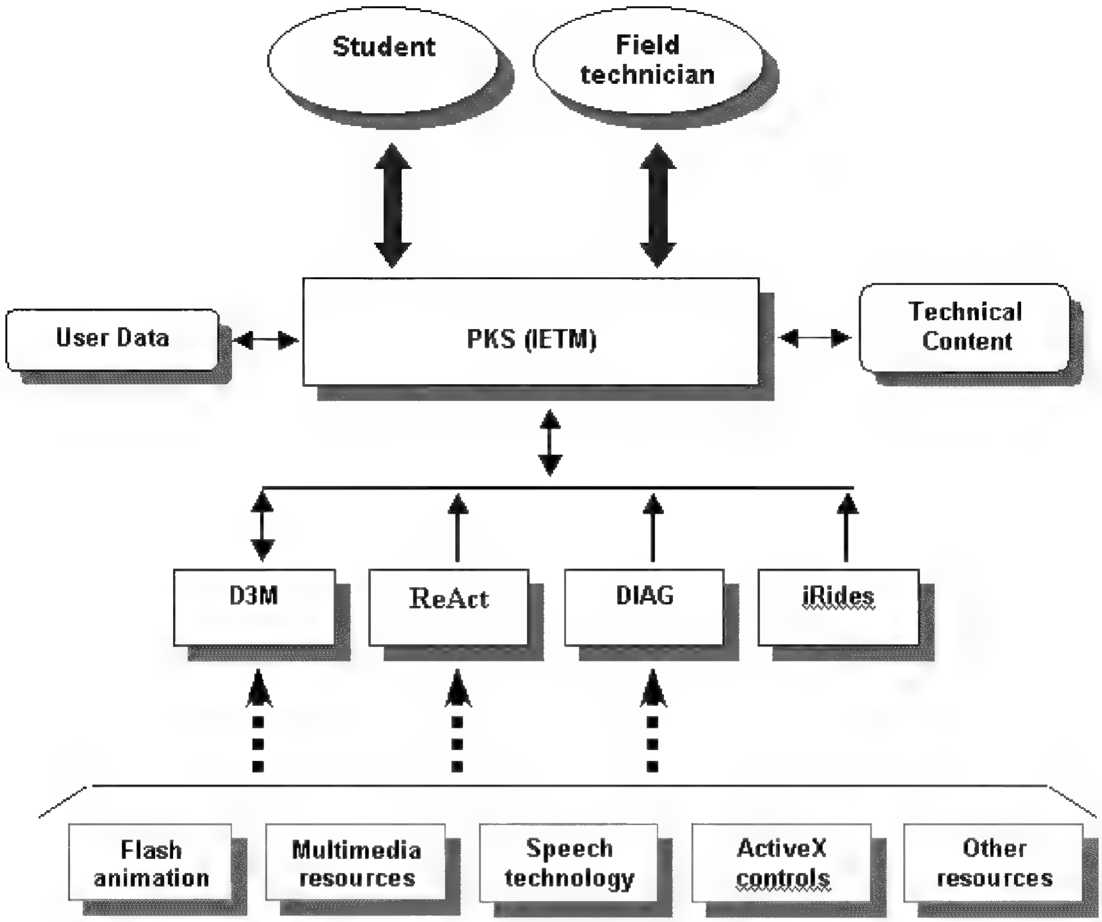

Figure 1: System Architecture (Towne, 2001)

With *PKS* and the incorporation of *DIAG* system models, schematics and diagrams within the technical manual can reflect the general system architecture as well as specific configurations under any condition such as the result of simulated malfunctions or user actions. This is in stark contrast to current applications using static diagrams that require the end user to mentally simulate component behaviors in order to determine the state of system elements and the connectivity under various conditions. Thus, conventional diagrams must support all learning or performance situations - they give no indication of signal flows or pressure status as the representation does not correspond to any real condition (see Figure 2).

Current ideas in terms of overcoming the short falls of displaying large diagrams on a computer display generally deal with manipulations to the viewing field. Such manipulations include scrolling, zooming, or fisheye functions (Wang & Liang, 2000). These methods provide better resolution and incremental viewing to a diagram, but still maintain a static display.

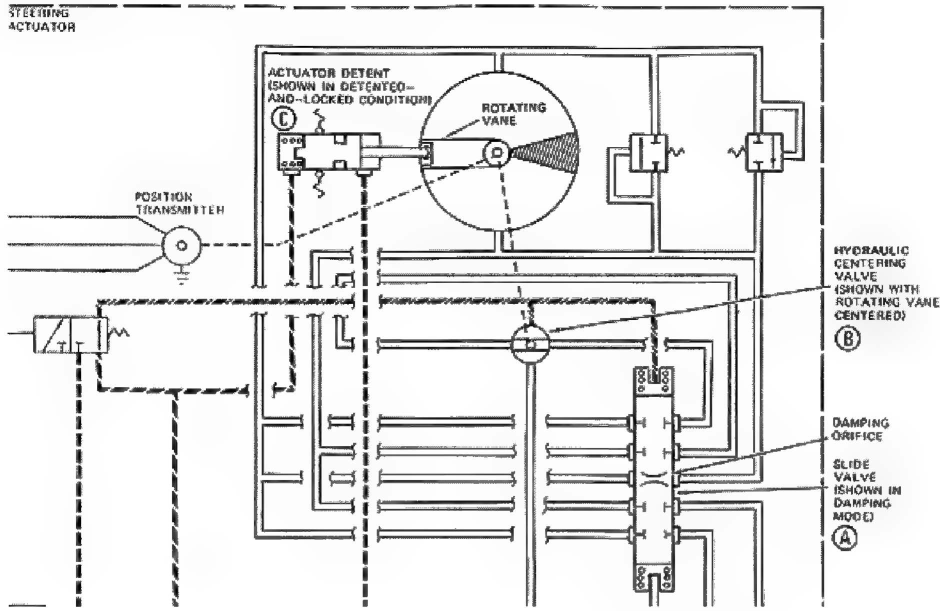

Figure 2. Conventional Diagram

With *DIAG*, diagrams change to support specified conditions (see Figure 3). For any given system mode, the diagram can explicitly portray system elements in the status that applies to current conditions. Thus, the use of system models within the IETM can dramatically reduce the cognitive workload a technician traditionally has when attempting to mentally represent the impact of a change in system status.

DIAG provides a number of functions that are not available when conventional diagrams are used. These functions provide the user with both performance support aids and learning tools. During FY03, these functions will be evaluated with fleet users.

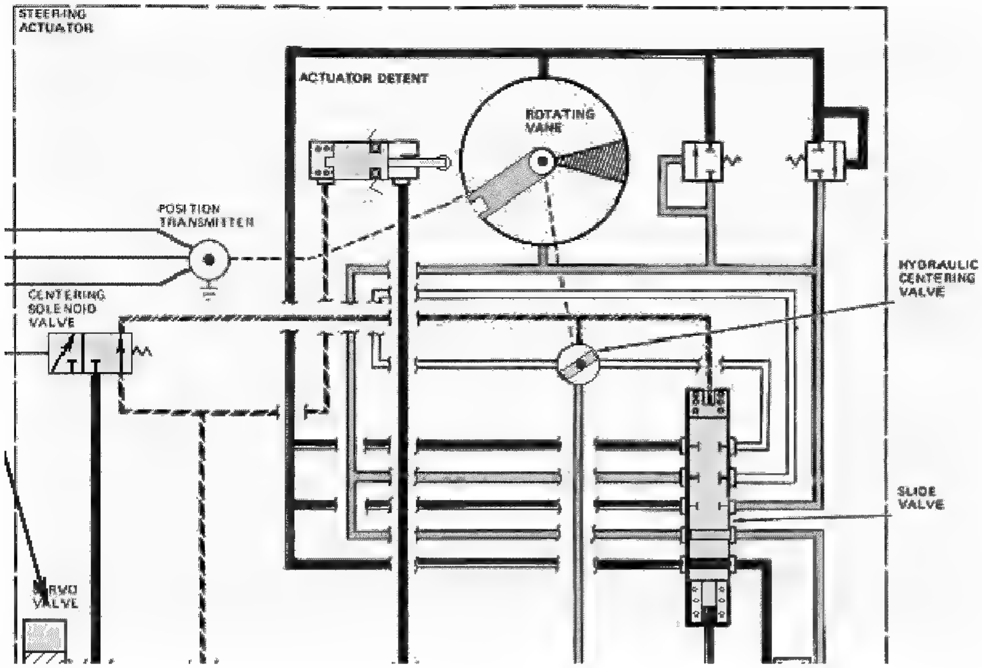

Figure 3. *DIAG* Diagram

Corrective Maintenance

When undertaking corrective maintenance tasks, *DIAG* is able to advise the field technician. Through interaction with the technician, *DIAG* will analyze initial observations that the technician has made. From that, *DIAG* will select a test to perform and request relevant information from the technician. After performing the test, the technician will report results back to *DIAG*. This process continues until *DIAG* recommends a repair action. When *DIAG* cannot isolate a single fault, it will report the fault area that it has localized (Towne, 2001). The projected benefits of this function include the potential to reduce time to isolate faults. An increased accuracy in locating actual faults can also lead to a reduction in the consumption of spare parts as greater accuracy leads to less guessing on the part of the technician and, therefore, less chance that good parts will be replaced.

DIAG diagrams reflect system connectivity. During corrective maintenance, *DIAG* provides an opportunity for the technician to learn how the system functions. Diagrams can be modified as the technician operates upon it or indicates a wish to see the diagram in a particular mode. The projected benefits of this function include a reduction in time needed to trace inputs/outputs and increased accuracy in tracing inputs/outputs.

DIAG also functions to support hyperlinks from schematic elements. Thus, when a technician wishes to locate technical information or learn the physical location of a schematically depicted part, hyperlinks are located on the diagrams to link the user to that information. Because the technician does not have to perform search operations within the document, this function is projected to reduce the time needed to access needed technical information.

Learning

Because *DIAG* can respond to user actions, it can allow the user to learn how the system functions in a particular mode and practice operating the target system in various modes. Thus, it supports both exploratory learning as well as guided instruction in operation and maintenance. Further, the *DIAG* system as well learns from diagnostic processes. All events are recorded in detail allowing *DIAG* to extract and incorporate new symptom information into its knowledge base.

Projected gains from these capabilities include a reduced time to understand how the system functions and to attain proficiency in operation. Further, repeated exposure to various diagnostic events through *DIAG* allows the technical manual to become a storehouse for domain-specific failure data (Towne, 2001).

LATENT SEMANTIC ANALYSIS (*LSA*) AND *SUPERMANUAL*

A potential -- but largely unrealized – tool for the user of electronic documentation provides the ability to search for, and access all of the information within a document that is relevant to the user's immediate needs. The reason why this promise remains largely unfulfilled is that much "electronic" technical material is not organized to facilitate task-oriented searches. Today the bulk of electronic documentation consists of paper documents that have been scanned into a PDF format. This format provides virtually no search capability. Recently created electronic documents authored in one of the existing word processor formats provide an automated word or term search capability that identifies every instance that the word or term is used in the document. A subset of these materials also include hyper-linked indexes, tables of content, and "hot" words and phrases that take the user to a glossary of definitions or other helps. Finally, some exemplary documents, in addition to the features described above, have been manually indexed to organize the material by level of detail, or level of relative difficulty to accommodate the specific needs of experts and novices.

All of these search schemes have a significant drawback that limits their usefulness. Simple word searches, and even manually indexed documents require the user to know (or guess) the specific words used by the author to represent a given idea. Thus, a search using a related word or term that is not actually used in the text in that form -- however, relevant to the topic -- would produce no results. *Latent Semantic Analysis (LSA)* provides a method for analyzing and successfully searching text material without requiring the searcher to decipher the author's particular terminology.

WHAT IS *LSA*?

Latent Semantic Analysis (LSA) can be described as: (1) A method for obtaining estimates of the substitutability of words in larger text segments, and of the meaning similarities among words and text segments, or (2) A model of processes and representations that underlie the acquisition and use of knowledge (Landauer, Foltz, & Laham, 1998).

LSA is, first, a statistical technique for describing and comparing the similarity of bodies of text. It does this by applying an automatic technique for extracting and inferring relations of expected contextual usage of words in passages of discourse. It does not require manually constructed dictionaries or ontologies. Rather, it uses only raw text that is parsed into words, and separated into meaningful passages such as sentences or paragraphs.

The idea underlying *LSA* is that the similarity of the contexts in which a word appears is a reliable indicator of the similarity of the meaning of words to each other. By processing a large sample of language, and specifying the contexts in which words occur, *LSA* can organize any set of these words in a high dimensional semantic space.

How does *LSA* work?

LSA is based on a mathematical technique closely akin to factor analysis. First, *LSA* uses the frequency with which two words are used within a portion of a text to establish a probabilistic measure of semantic association. In the first step the text is represented as a two-dimensional matrix in which the rows stand for unique words and each column stands for another word, a sentence, a paragraph, or some other context. Each cell contains the frequency with which the word of its row appears in the passage denoted by its column. Thus, the matrix has the form of a large rectangular table with a large number of rows and an even larger number of columns. The cell entries are then weighted by a function that expresses the word's importance in the passage and the degree to which the word type carries information in the domain (Lee, In press).

Next, *LSA* applies a statistical technique called *Singular Value Decomposition (SVD)* that compresses the co-occurrence information into a smaller space. In *SVD*, a rectangular matrix is decomposed into the product of three other matrices. The first derived matrix describes the original row entities as vectors of derived orthogonal factor values. The second derived matrix describes the original column entities in the same way. The third matrix is a diagonal matrix containing scaling values such that, when the three component matrices are multiplied, the original matrix is reconstructed. The final step is to identify relationships that underlie the pattern of occurrence of words across passages. In theory, semantically related words and passages will load on similar dimensions, although they may share no common words (Lee, Submitted).

How has *LSA* been used?

LSA was originally developed for the task of information retrieval, but has been used to simulate a variety of language tasks.

- It has taken the Test of English as a Foreign Language and performed as well as non-native English speakers who were successful college applicants.
- It has shown an ability to learn words at a rate similar to humans. It has even graded papers as reliably as human graders (Landauer, Foltz, & Laham, 1998).
- It has been used as a mechanism for evaluating the quality of student responses in an intelligent tutoring system and its performance equals that of human raters with intermediate domain knowledge.

LSA approximates human judgments of overall meaning similarity. Based on a corpus of 68,000 words, *LSA* acquired a working vocabulary at the same rate as school children (Landauer & Dumais, 1997). *LSA* also provides a tool for extracting the essential semantic components of information.

LSA has been used to interpret and score a student's natural language input in an intelligent tutoring system (*ITS*). The adequacy of *LSA*'s reflection of human knowledge has been established. For example,

- its scores overlap those of humans on standard vocabulary and subject matter tests,
- it mimics human word sorting and category judgments,
- it simulates word-word and passage-word lexical priming data, and
- it accurately estimates passage coherence, learnability of passages, and the quality and quantity of knowledge contained in an essay (Wiemer-Hastings, 2000).

Additional Research

Landauer and Dumais (1996, 1997) have proposed that *LSA* constitutes a fundamental computational theory of the acquisition and representation of knowledge. As a statistical method for characterizing word usage, *LSA* produces measures of word-word, word-passage, and passage-passage relations that correlate with human behavior involving word association or identifying semantic similarity.[1] Landauer and Dumais maintain that *LSA*'s underlying mechanism can account for the ability of people to acquire more knowledge than is available (Landauer & Dumais, 1996; 1997). The principal support for this claim has come from using *LSA* to derive measures of the similarity of meaning of words from text. Because of this, and other capabilities similar to human cognitive performance, Landauer and Dumais have proposed *LSA* be used to model, test, develop, and explore fundamental theoretical implications of human information processing.

SUPERMANUAL

SuperManual is based on the empirically validated design of the *SuperBook* reference-manual browser developed at Bellcore in the early 90s (Landauer, 1995). *SuperBook* increased speed and accuracy on information-dependent tasks by large factors, and was used by thousands of telecommunications employees. *SuperBook's* design provided a number of innovative techniques for displaying technical information such as the dynamic fisheye table of contents and specialized search functions. One critical aspect of the development of *SuperBook* was the iterative test and design methodology (Landauer, 1995). As shown in Figure 4, several iterations of *SuperBook* were required before finding a design that was superior to paper-based products. This figure illustrates the efficiency of finding facts in a technical document with the original printed version and with three successive versions of the *SuperBook* text browser.

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[1] This correlation may be the result of the word choice of the writers of the text corpus, which reflects the way people typically representation meaning, or -- vice-versa -- peoples' representations of meaning may reflect the statistics of word patterns they have previously read and heard.

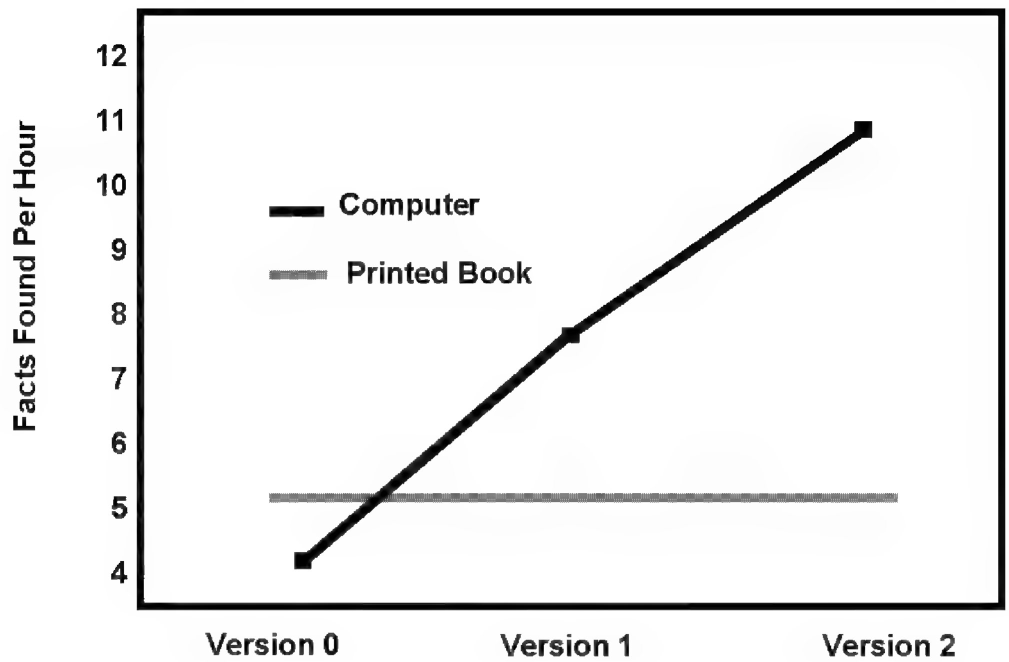

Figure 4: *SuperBook* Iterative Design (Landauer, 1995).

Under the *SuperBook* program, a number of features were researched. In some cases, those features are instantiated in current applications. For example, in *SuperBook*, a dynamic "fisheye" table of contents is created from the heading structure of the text. The table of contents is displayed in the left window and is organized by top-level headings that can be opened by mouse clicks to reveal lower level sub-sections. This is a now a common convention in electronic documentation. Other features that were proven to be sub-optimal (e.g., Boolean queries) are still in use today.

The objective of the current *SuperManual* research is to design and prototype better ways to dynamically organize, present, and customize information for particular tasks and individual maintainer knowledge and levels of expertise. The goal is to make the next generation of IETMs much more effective as job performance aids by improving the maintainer's ability to find, use, and learn from their task-relevant contents. The descriptions below summarize some of the current research issues under an ONR funded Phase II Small Business Innovative Research (SBIR) award. Further details and a system demonstration can be found at http://knowledge-technologies.com/onr.html.

Meaning-Based, Natural Language Search

As described above, *LSA* is a key component to the *SuperManual* project. *LSA* represents a major innovation to the original *SuperBook* design. *LSA*'s most visible impact in *SuperManual* is the meaning-based, natural language search capability. Search, or "find" functions in current electronic documents (e.g., Adobe) target each instance of that exact word(s) in a linear fashion throughout the document. Figure 5 shows a word search carried out within an Adobe document. The user repeatedly presses the "next" button until the desired area of the document or content is found.

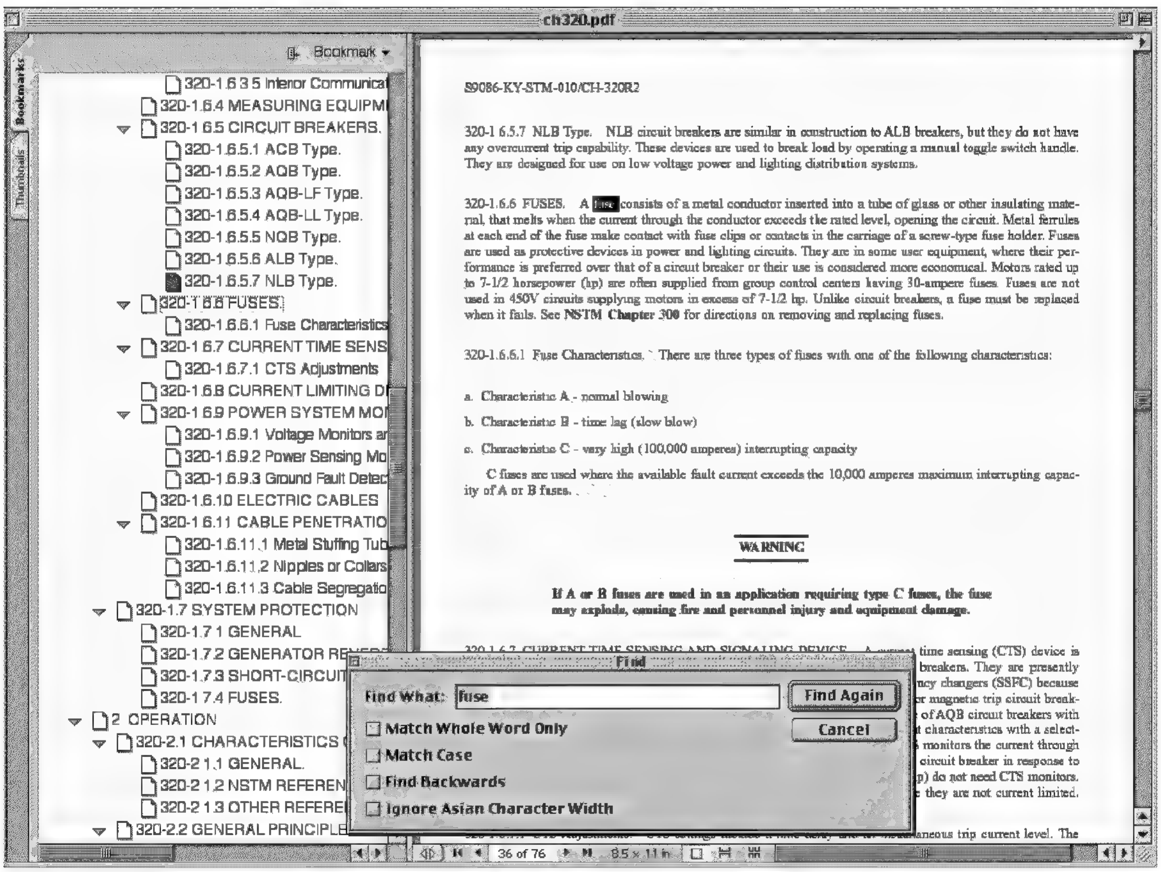

Figure 5. Adobe Word Search

Unlike a traditional search, *SuperManual* (as did *SuperBook*) shows all occurrences of the search terms posted against the dynamic table of contents. Figure 6 shows the same search within a *SuperManual* version of this document. Every place that the query word appears in the document is indicated in the table of contents, thus providing a context for the user to select the appropriate section to select. Furthering this in *SuperManual* is the addition of *LSA* – not only will the table of contents show

where that exact word exists in the document, it will also show areas where meanings closely associated to the query term also exist.

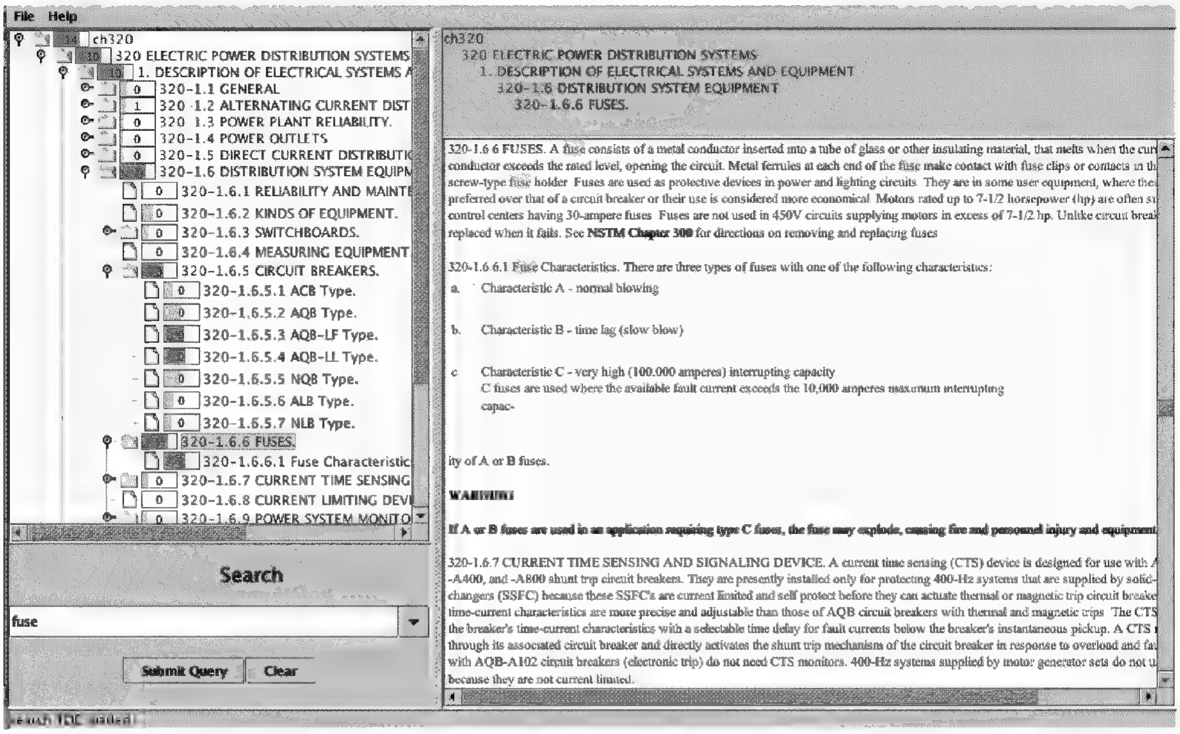

Figure 6. ***SuperManual*** **Search**

Minimum Path to Knowledge

When preparing to perform a specified maintenance task, technicians may desire a review of the supporting information for that task. This review might be significantly time intensive as it requires skimming through an entire document to find applicable sections. Currently under investigation in the *SuperManual* program is an algorithm, termed "*Optimin*," designed to find the sequence of subsections or paragraphs in a manual that will propose a path from either its beginning or from a user-selected starting point to the target section. The suggested sequence of steps is then displayed in the dynamic table of contents. The results of this search would be used as a guide to finding the needed information to perform a given task.

Keyword and Sentence Summaries

The *LSA* generated keyword/sentence summary will provide an icon at the end of a table of contents title. When this icon is clicked, a pop-up box will display either a 3 to 5 word automatically generated keyword summary or a best-sentence summary of the section. The "best-sentence" is generated by *LSA* by comparing the meaning of

each sentence in section with each other sentence and finding the one whose average similarity to all others is greatest.

Adaptive Indexing

When using a traditional search convention, such as a find feature, each instantiation of the term or terms can be found. However, there is often the case when the information needed may not be the exact term used in the search. The system keeps track of the words that users try that do not succeed. If and when the user finally finds a sought item, the system asks whether some of the user's words that did not find the desired content, but should have, ought to be added to the list of index terms for that item. If the user concurs, the new key words are promoted to definitive pointers that remain available for that and other users in the future.

SPOKEN LANGUAGE INTERFACE AND WEARABLE COMPUTING

In recent years, technology has progressed to enable mobile computing. Certainly, platforms such as the personal palm computers provide access to data, email, and scheduling applications. However, for complex operations such as corrective maintenance actions, the full capability of mobile computing has yet to be exploited. The requirements of maintenance are vastly different from those of applications on palm computers. To say the least, the real estate available on hand-held computers is insufficient. Further, the key to mobility is the ability to perform hands free of the computer. The challenges associated with developing such a system is the advanced capabilities, such as spoken language interfaces and the delivery of IETM information on a wearable computer that is functional, reliable, and safe.

Currently, two inter-related capabilities are being investigated through the Intelligent Performance Support and Training program by researchers at Carnegie Mellon University (CMU). The first, spoken language interface, relates to the voice interaction mode by which technicians extract information from and input information to the technical manual. Closely related to this is the capability that allows the technician freedom of movement without losing contact with technical documentation. Wearable computers with head-worn displays provide this mobility. The objectives of the CMU research are to:

- assess the utility of spoken language dialog and adaptive design of advanced IETM interfaces;
- conduct experiments and field usability evaluations to rapidly and systematically increase knowledge about adaptive, advanced IETM interfaces; and
- develop initial principles of multi-media advanced IETM systems in terms of interaction options to support training and performance aiding and delivery on mobile/wearable computers.

SPOKEN LANGUAGE INTERFACE

The Carnegie Mellon Speech Group has a long history of developing and researching speech systems. In 1976, the *Dragon/Harpy* system investigated the recognition of a large vocabulary. Speaker-independent continuous speech was researched with the *Sphinx* system in 1987. Spoken language information retrieval was achieved with the *ATIS* system, and the *Speech Wear* system addressed wearable speech systems. Most recently, the DARPA *Communicator* program addresses dialog-based problem solving. Using a travel-planning tool accessible through phone at 1-877-CMU-PLAN, callers can plan travel through the assistance of *Communicator*. Data are collected to analyze dialogs as they relate to a problem-solving domain. Research

issues include architectures for spoken language systems, dialog management, and language generation.

The current research is working with the Carnegie Mellon Speech Group's *Symphony* System. The goal is to provide a natural spoken interface – not a simple mapping between spoken words and graphical user interface elements. The vision of the *Symphony* program is to allow for natural, voice-driven access to technical manual materials. To support the technician, the system must provide assistance (other than reading the technical manual) in diagnostic procedures. That is, it must provide a mentoring capability that will shadow maintenance activities, offer procedure advice and provide historical data.

WEARABLE COMPUTERS AND OPTIMIZED DISPLAYS

Prior research conducted for ONR provides valuable input to inform future design efforts. In particular, data were collected at China Lake Naval Weapons Station from 8 maintainers of the F/A-18 aircraft (Siegel, Hyder, Moffett, & Nawrocki, 2000). Two IETM interfaces were studied. The first was a windows/web browser design typical of current IETM interfaces. The second was a highly graphical interface. Both interfaces were used in conjunction with a dial I/O device developed at CMU and a head-worn display attached to the maintainer's cranial cap (see Figure 7).

Figure 7. Wearable Computer with Voice and Dial Interface

This study concentrated on three specific IETM challenges: navigation, use of magnification, and cautions. The graphical interface was designed to enhance these challenges. Specifically, this interface design displayed procedures using a navigational frame providing high level steps as well as access to lower level details that might be needed by a novice. The display completely hid all other operating system buttons (e.g., Windows "Start" button) that could potentially lead to confusion or frustration if inadvertently selected by novice computer users. The display utilized an icon that allowed images to expand the width of the screen, providing magnification and scrolling options as well. Finally, cautions were embedded as steps and displayed as icons. As the step is selected, the alert appeared – however, it did not obscure procedures, as is common in other IETMs.

While it is not possible to make conclusions given a small sample size, the data from this study suggest that novices preferred the web/browser design – perhaps because it is more like paper documentation. Experts, however, were more likely to prefer the graphical design and stated that this design gave them a better sense of the whole task. All of the participants agreed that current alert displays are less than optimal and preferred methods of displaying alerts without obscuring the display. Similarly, all participants indicated a need for magnification and scrolling for small images and large schematics.

While the IETMs studied received positive feedback, comments as to what the maintainers liked least included the dial I/O device and the display. There were instances noted where maintainers would turn the dial too quickly and jump over information. Further, there was note of uncertainty as to how to navigate backwards or forwards. The mobility and hands-free work afforded by the wearable were enthusiastically welcomed. However, there is additional research necessary to find the optimal hardware components. A more recent iteration of CMU's wearable computer, "SPOT", is presented in Figure 8. Specifications of the SPOT system are provided in Table 3.

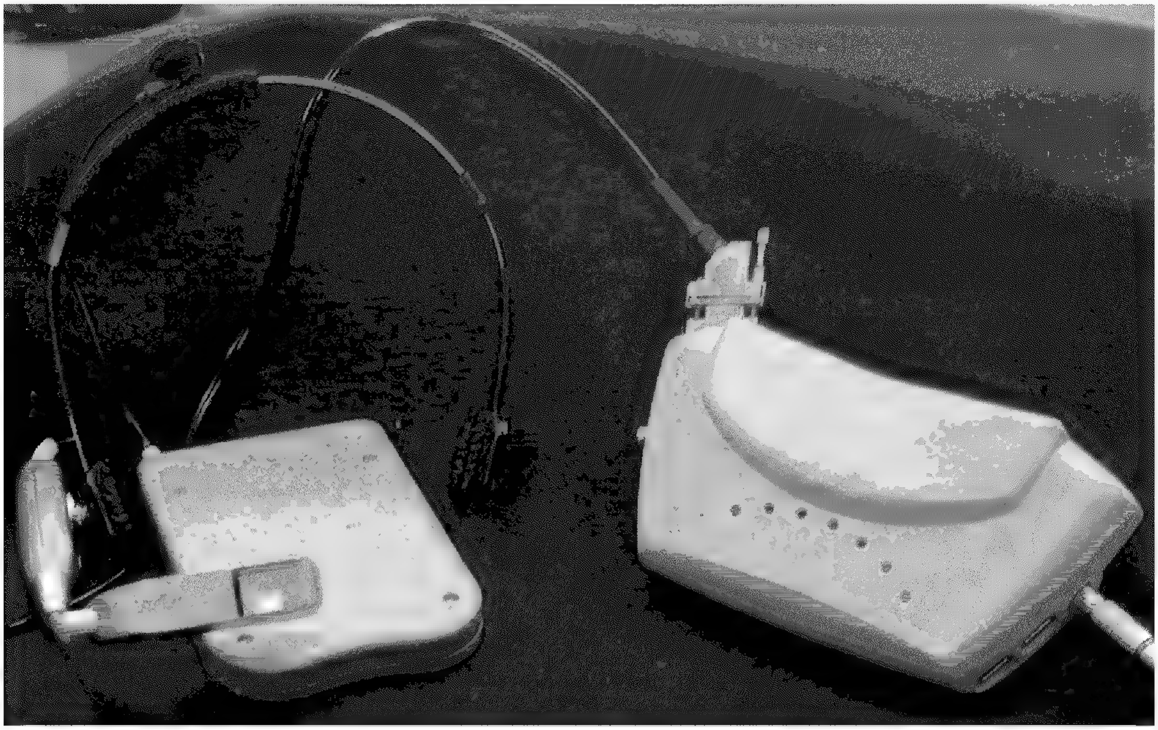

Figure 8. SPOT Wearable Computer

SPOT SPECIFICATIONS	
Processor	206 MHz SA-1110
Companion Chip	SA-111
Memory	256 MB SDRAM
Flash RAM	64 MB
PCMCIA	1 Type-II
Compact Flash	1 Type-II
Display	DVI 1.0 Output
Serial I/O	1 RS-232
USB	1 Type A
IEEE-1394	2 Powered Ports
Power Monitoring	Channels
Audio	Stereo In/Out

Table 3. SPOT Specifications

WORKSHOP CONCLUSIONS

The NAVAIR Orlando, Training Systems Division, hosted an Office of Naval Research (ONR) sponsored workshop addressing research and development issues for advanced Interactive Electronic Technical Manuals (IETMs). The purpose of this workshop was to provide a forum for academia, government, and Fleet personnel to discuss ongoing and planned research related to advanced electronic maintenance documentation for performance support and training.

The workshop highlighted several areas that currently pose difficulty for developers and users of IETMs. Of those issues, several are being addressed in the current research effort: troubleshooting aids; search, navigation and interaction tools; and mobility. The development and evaluation of these products are progressing separately. As they mature, they will be integrated to work together. As initially planned, that collaboration was to begin in FY04. This plan did raise some concern related to the fact that a myriad of proprietary software products exists today. The notion of further development of three separate products without effort related to integration was seen as increasing the likelihood of ending up with three separate systems. Accordingly, collaboration efforts were moved up from FY04 to FY03.

The presentation and demonstration given by Dr. Towne highlighted the use of a model-based approach to intelligent tutoring within an IETM. Clearly, the *DIAG* component of the *PKS* system provides enormous potential in making technical documentation less mentally demanding on the technician. However, concerns were expressed that the development of a *DIAG* model is time-intensive and requires the appropriate knowledge of the system and *DIAG* software. Evaluations conducted during FY03 will hopefully provide the needed data to show the benefit of a *DIAG* IETM. As the use of computer-aided design (CAD) systems increase, there is potential to convert system information directly to a modeling program such as *ReAct*.

Data presented from the Naval Safety Center indicate publications are a factor in 25% of aviation mishaps. Further work to define the nature of the impact of publications on aviation mishaps is now underway under the support of this research effort. Additional data from the Naval Safety Center show that the updating process for aviation technical manuals is excruciatingly slow. Similar data exist for the surface technical manual community. Currently, changes to technical manuals begin with a "Technical Manual Deficiency Report," located at the rear of each manual. Technicians complete the report describing the problem or the change needed and submit the report to the "In-Service Engineering Agent (ISEA)" for that piece of equipment. If the problem is safety related, then the change might happen rather quickly. If the change is not safety related and the equipment is legacy (i.e., not funded), changes build up and might get implemented in time (i.e., every 5 years or so). However, it is likely that without funding, changes will not be validated and thus, go ignored.

Even with new equipment, technical manual changes are not made often, as the cost of engineering verification is still an issue. The ISEA would probably wait until there were a number of deficiency reports before funding an engineer to verify the changes. The verified changes are currently sent out and are recorded on a 'change page' at the beginning of each manual.

While the updating and change processes that a manual must go through are not the focus of this current effort, the ability of maintainers to quickly forward potential erroneous information and the ability of the technical manual authority to reply with updated information must be available within any IETM. Further attention will be given to this area as progress begins on the development of an authoring tool.

The integration of device models within technical manuals provides potential benefits in alleviating some of the burden of technical manual updates. In fact, ***initial*** deficiencies could be reduced dramatically. One issue raised recently in the development of the *PKS/DIAG* demonstration for the S-3B Nose Wheel System was the inaccuracy of the original technical manual. This problem became evident when the model generated for the system did not behave in accordance with expectations. Subsequent consultations with subject matter experts revealed the inaccuracy in the model stemmed from statements in the technical manual that were erroneous. Once these errors were corrected in the model, the model behaved correctly. Thus, if future manuals had the benefit of device models, errors in the documentation could be detected prior to release.

A problem clearly evident with current IETM products is the avoidance shown by technicians to use IETM products that are perceived as complex and unintuitive. For certain, technology has accelerated tremendously and has provided products that remain untested for effectiveness and efficiency. The lack of use of current IETMs noted at the workshop underlies the importance of applying new technology to IETMs. Current capabilities utilize computers as a ***substitute for paper*** rather than capitalizing on computing resources. IETMs must allow computers to do functions that computers can do ***better*** than paper. There are large gaps that the research community must fill to truly capitalize on the promise of the electronic environment. The benefits of reduced space needed to house documentation and reduced weight for heavy paper manuals will be quickly eroded when copy machines and associated paper products are needed throughout ships' spaces. Further, the benefits of rapid updates to electronic documents are negated when technicians print paper versions and thus, ignore subsequent updates to the electronic version.

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